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Research on Advanced Mathematics Teaching Models in the Digital Era

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ABSTRACT

Advanced Mathematics is a public basic mathematics course. The current teaching model predominantly continues to overemphasize calculation and problem-solving, which hinders the comprehensive development of students' mathematical thinking. Moreover, redundant teaching resources and insufficient accessibility of online materials have further compromised teaching effectiveness. To address these issues, we have introduced a student-centered educational approach using a "Four-Drive, Dual-Track Integration" model. The "Four Drives" represent four core motivators that provide sustained momentum for teaching innovation. The "Dual Track" refers to the parallel use of two instructional modes: a blended format combining online self-directed learning and offline classroom teaching. "Integration" aims to achieve a deep convergence of theory and practice, knowledge delivery and competency cultivation, as well as online and offline interactions, thereby building an interactive learning community involving both instructors and students. Through the Four-Drive framework supported by the Dual-Track model, this reform ultimately enhances students' mathematical thinking, creativity, and problem-solving skills, effectively meeting the demands for high-quality talent under the "Four New Initiatives" in the new era. Positive practical outcomes and successful implementation have been observed.

KEYWORDS: *Artificial Intelligence; Advanced Mathematics; "Four-Drive, Dual-Track Integration" Model.*

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I. INTRODUCTION

In recent years, breakthroughs in key technologies across various fields-from artificial intelligence and big data to aerospace and national defense security, from bio-medicine and new energy to marine engineering, financial technology, and advanced manufacturing-have all relied on the support and driving force of mathematical science. The "Work Plan for Strengthening Mathematics Scientific Research," jointly issued by the Ministry of Science and Technology, the Ministry of Education, the Chinese Academy of Sciences, and the National Natural Science Foundation of China, further emphasizes the foundational role of mathematics in natural sciences and major technological innovations. Against this backdrop, some scholars have focused on innovating teaching models for Advanced Mathematics [1-3], while other teaching practitioners have explored instructional content and methods [4-5]. Aligned with our university's positioning, which features logistics and circulation as distinctive disciplines alongside multidisciplinary coordinated development, systematically advancing the reform of teaching and learning strategies in the Advanced Mathematics course holds significant practical importance for cultivating high-quality applied talents with a solid foundation in mathematics and science.

As a public foundational course offered to first-year students in science, engineering, economics, and management disciplines at our university, Advanced Mathematics covers core calculus topics such as limits, derivatives, differentiation, integration, and series. It not only serves as the theoretical basis for subsequent specialized courses but also acts as an essential analytical tool supporting fields such as logistics engineering, information management, supply chain optimization, and economic statistics. Due to the wide range of majors, diverse student

backgrounds, and varying levels of mathematical preparedness among students, some learners exhibit limited comprehension of abstract mathematical concepts and insufficient motivation, which collectively impacts overall learning outcomes. At the same time, a subset of students with solid foundations and aspirations for further studies demand more advanced mathematical training. This diversity in student readiness creates a practical need for tiered and categorized instruction. To accommodate the needs of different majors and student levels, our university has established a stratified Advanced Mathematics curriculum, comprising three compulsory courses: Advanced Mathematics A (80+80 class hours), Advanced Mathematics B (64+64 class hours), and Advanced Mathematics C (80+80 class hours). These courses are co-taught by faculty from the public basic courses department and related specialized disciplines. Additionally, to support students' personalized development and skill enhancement, elective courses such as Mathematical Modeling and Simulation and Advanced Mathematics have been introduced, forming a two-tier "foundation + extension" course structure aimed at achieving discipline-specific and student-centered teaching. However, due to disparities in student preparation and learning habits, the pass rate for the Advanced Mathematics course remains unsatisfactory. Since the spring semester of 2021, our university has implemented a "dual-pass requirement", stipulating that students must achieve a score of 60% or above in both regular assessments and the final exam. While this system strengthens process management, it also reveals that some students fail regular assessments due to factors such as poor attendance or low midterm grades, thereby losing eligibility for the final examination, which ultimately affects their overall course pass rate. Poor examination performance not only hinders students' academic progress but also undermines their learning confidence and motivation.

Therefore, against the national backdrop of strengthening the strategic importance of mathematics, and in light of our university's disciplinary characteristics and student profile, further optimizing the teaching content, innovating instructional methods, and improving evaluation mechanisms for Advanced Mathematics have become crucial to enhancing course teaching quality and supporting the cultivation of high-quality applied talents.

II. Teaching Objectives of the Advanced Mathematics Course

This course aims to help students systematically grasp the fundamental concepts, theories, methods, and computational skills related to functions and limits, calculus of functions, differential equations, and infinite series, while also providing a preliminary understanding of mathematical modeling. Through this course, students will enhance their mathematical literacy and practical application abilities, laying a necessary foundation for subsequent studies in linear algebra, probability theory, and other specialized courses, as well as for further expanding their mathematical knowledge. The course also emphasizes the integration of ideological and political education into theoretical instruction, guiding students to understand the historical development and cutting-edge trends of advanced mathematics, thereby fostering the development of sound moral character.

Knowledge Objectives: Through this course, students will systematically master the basic concepts, theories, and methods of core topics in advanced mathematics, including functions and limits, calculus, differential equations, and infinite series. They will develop solid computational skills and preliminary mathematical modeling abilities, establishing a necessary foundation for subsequent courses such as linear algebra and probability theory, as well as for further expanding their mathematical knowledge.

Ability Objectives: Students will cultivate strong abstract generalization skills, rigorous logical reasoning abilities, proficient computational techniques, and independent learning capabilities. They will be able to construct mathematical models for real-world problems in daily life and professional contexts, creatively propose solutions, and utilize mathematical methods to perform necessary calculations, analyses, and judgments.

Quality Objectives: Students will gain an understanding of the historical development andcutting-edge developments of advanced mathematics, develop active mathematical thinking, a rigorous and truth-seeking scientific attitude, and a scientific worldview. The course aims to foster students' moral character and comprehensive mathematical literacy.

III. Teaching Reform Measures for the Advanced Mathematics Course

Guided by the student-centered educational philosophy that emphasizes teacher-student and student-student interaction, we have designed a "Four-Driven, Dual-Track Integrated" teaching model. This model uses mathematical modeling for solving real-world problems as a main thread, connecting the course content with practical issues and cases. Through this approach, students genuinely recognize that mathematics is derived from real-life problems, and that mathematical thinking, in turn, can be used to address practical challenges.

3.1. Four-Driven: Sustained Momentum for Teaching Reform

1. Research Integration Drive

Teaching is enhanced by research feedback. By introducing cutting-edge research outcomes-such as applications of differential equations in optical fiber communications and bioenergy, as well as series applications in graphics processors-students' scientific horizons are broadened. In classroom instruction, students are guided not only to think about model improvements to cultivate a research-oriented mindset, but also to directly apply research tools such as Mathematica to calculus computations and graph plotting, enabling them to intuitively experience the effectiveness of information technology in solving practical problems. Additionally, training in literature retrieval is combined with platforms such as college students' innovation and entrepreneurship projects to guide students through the research process, systematically fostering their innovative awareness and exploratory abilities. Students are also encouraged to participate in discipline competitions and science popularization activities, including the National College Mathematical Contest in Modeling, MathorCup Mathematical Modeling Challenge, College Mathematics Competitions, National College Data Analysis Skills Competition, and the "Math Cup" Science Popularization Competition, thereby promoting teaching, learning, and research through competitions.

2. Ideological and Political Education Drive

Ideological and political education is integrated throughout the teaching process in a subtle, "moistening" manner: by incorporating mathematical history, stories of mathematicians, and traditional culture, a series of ideological case videos have been produced to imperceptibly cultivate students' patriotic spirit and scientific ethos. Real-time cases related to technological contributions to the nation and current social issues are used to guide students to pay attention to contemporary developments and establish correct values. Teachers also lead by example, practicing core socialist values through their words and deeds, thereby inspiring students' intrinsic motivation. The main ideological cases introduced in the course are listed in Table 1.

Table 1 Ideological and Political Education Cases

Knowledge Point	Case Name	Ideological and Political Focus & Educational Objective
Limit/ Infinitesimal	Liu Hui's "Cyclic Division Method"	Demonstrates the mathematical wisdom of the Chinese nation and builds cultural confidence. By studying the "replace curve with straight lines" and limit thinking embodied in the method, students are guided to recognize the dialectical relationship between quantitative and qualitative change, as well as the persistent spirit of pursuing truth.
Limit Concept	"A staff of one foot, cut it in half daily, the process can continue indefinitely"	Vividly illustrates the dialectical relationship between the infinite and the finite, and between quantitative and qualitative change. Guides students to view problems from a dialectical and developmental perspective, understanding the laws of motion and change.
Fundamental Theorem of Calculus	Zu Chongzhi and Pi	Promotes the rigor and innovative spirit of ancient scientists. By introducing Zu Chongzhi's achievement of calculating Pi to 7 decimal places, students are inspired to develop national pride and the ambition to serve the country through science and technology.
Maxima/Minima Problems	BeiDou Navigation Satellite System	Introduces cases like satellite orbit optimization and positioning accuracy optimization when teaching maxima/minima applications. Emphasizes the importance of independent innovation and teamwork, motivating students to serve national strategic needs.
Maxima/Minima Problems	Resource Allocation Optimization	Introduces cases like production cost minimization and profit maximization when teaching maxima/minima applications, extending to resource conservation and efficiency improvement in social development. Cultivates students' green development理念 and benefit-awareness.

History of Calculus	Newton and Leibniz	Introduces the history of calculus' creation, guiding students to recognize that scientific discovery builds on previous work. They should learn from great innovators while respecting intellectual property and academic norms.
Differential Equations	Discovery of Neptune	Neptune was not found by chance; Adams and Le Verrier predicted its existence accurately through mathematical calculation-"the planet discovered by the tip of a pen." Demonstrates the predictive power of mathematical theory, fostering innovation consciousness in pursuing truth and exploration.
Differential Equations	Infectious Disease Model (SIR Model)	Introduced when teaching differential equations, shows how mathematics applies to public health decision-making. Cultivates social responsibility, scientific literacy, and awareness of applying knowledge to serve society.
Curvature / Radius of Curvature	Engineering Rigor: Rail and Road Design	Introduces cases like mountain road curve design and rail transition curves when teaching curvature. Emphasizes that mathematical calculation is the foundation of engineering safety, cultivating rigorous, meticulous, and responsible engineering ethics.
Infinite Series	"Grains of Rice on a Chessboard" and Exponential Growth	This engaging mathematical story serves as an effective vehicle to illustrate the principle of "addressing issues before they escalate," prompting rational reflection on resource allocation and desire management, thereby guiding students to establish a concept of sustainable development.

3. Information Technology Drive

The course fully utilizes modern information technology, leveraging MOOC platforms to break down knowledge points into micro-videos accompanied by tiered quizzes. This supports students in previewing and reviewing content according to their needs, effectively enhancing classroom efficiency. Through interactive features such as real-time attendance tracking and on-the-spot exercise projection, instant feedback and interaction between teachers and students during the teaching process are achieved. The deep integration of information technology not only meets the personalized learning needs of students at different levels but also provides a solid foundation for blended online and offline teaching. For example, a survey was conducted to investigate the absenteeism reasons of 72 students over a two-week period. In Figure 1, A, B, C, and D represent the proportion of students attributing their absence to the course being too difficult, the fast pace of teaching, lack of interest in mathematics, and participation in other club activities, respectively. The finding that 65.2% of students missed class due to club activities enables timely understanding of student situations and facilitates adjustments in teaching methods and pacing.

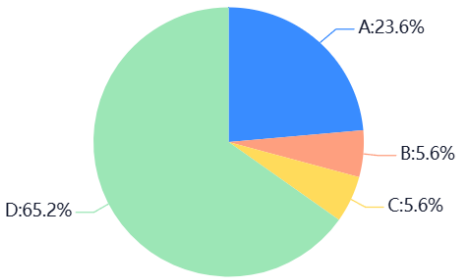

Figure I. Survey Results on Student Absenteeism

4. Process Evaluation Drive

To guide students in valuing the learning process, the course has continuously reformed its assessment methods. The weight of the final exam score has been significantly reduced from 70% to 50%, while the weight of the midterm exam has been increased to 25%, and regular performance (also 25%) has been strengthened. This forms a diversified process evaluation system encompassing "attendance + platform learning + tests + assignments." Leveraging MOOC-based teaching platforms, the entire learning process of students-including online self-directed learning (MOOC study and tests), offline classroom performance, and post-class assignments including major chapter tasks-is recorded and managed. The system primarily assesses students' independent online

learning, their understanding and mastery of knowledge in class, and their ability to solve problems after class using acquired knowledge. This approach effectively avoids last-minute cramming and encourages students to develop good learning habits of gradual and solid mastery of knowledge points.

3.2. Dual-Track: Blended Online and Offline Teaching Model

This course adopts a blended teaching model that combines online and offline learning. In the online self-directed learning phase, students independently schedule preview and review using resources such as micro-videos and tiered quizzes provided on the MOOC platform, effectively fostering self-study skills. Offline classroom teaching focuses on interaction and practice, using real application cases and mathematical modeling problems as starting points to carry out heuristic and inquiry-based teaching. The deep integration of the two forms a virtuous cycle in which "online resources support offline learning, and offline interaction deepens online understanding," significantly improving teaching efficiency and learning depth.

3.3. Integration: Multi-Dimensional Deep Integration Goals

The ultimate goal of the reform is to achieve deep integration across multiple dimensions. In terms of integrating theory and practice, real cases such as infectious disease models and drug degradation guide students to construct models based on practical problems and apply mathematical knowledge to solve them, strengthening the combination of learning and application. In terms of integrating knowledge and competencies, knowledge impartation is organically combined with the cultivation of core literacies such as research thinking, modeling skills, and information technology application, promoting students' transformation into innovative practitioners. In terms of online-offline integration, an information technology-bridged integrated learning community of "resources – classroom – feedback" has been constructed, ultimately achieving a systematic upgrade of the teaching and learning model.

IV. Analysis of Teaching Effectiveness in the Advanced Mathematics Course

1. Significant Improvement in Student Academic Performance

Comparative analysis of final exam scores shows that after the adjustment of the assessment method, the pass rate for the final exam in the 2024-2025 academic year exceeded 80%, and the excellence rate exceeded 25%. See Table 2 for details.

Table 2 Student Performance in Advanced Mathematics Final Examinations (2023-2025)

Semester	Course Name	Excellent (A)	Good (B)	Satisfactory (C)	Pass (D)	Fail (F)	Pass Rate
		90~100	80~89	70~79	60~69	<60	
24-25-2	Advanced Mathematics A2	27.16%	19.75%	16.36%	18.21%	0.31%	81.48%
24-25-1	Advanced MathematicsA1	33.84%	25.30%	15.24%	14.94%	0.30%	89.33%
23-24-2	Advanced MathematicsB2	11.90%	15.48%	17.86%	27.38%	27.38%	72.62%
23-24-1	Advanced MathematicsB1	24.13%	16.46%	15.50%	18.72%	25.18%	74.82%

2. Abundant Achievements in Competitions

In recent years, undergraduate students from our university have consistently achieved outstanding results in various mathematics-related competitions. In 2024, under our guidance, students participated in the Asia and Pacific Mathematical Contest in Modeling (APMCM) and won one National Second Prize. In the Chinese session of APMCM, they obtained one National Second Prize and two National Third Prizes. In the MathorCup Mathematical Modeling Challenge, they secured one Provincial Second Prize. In the National College Mathematical Contest in Modeling, they earned one Provincial First Prize. In the National Statistical Modeling Contest for College Students, they achieved one Provincial First Prize. In the National Mathematics Competition for College Students, they won two Provincial Second Prizes and one Provincial Third Prize. In the National Data Analysis Skills Competition for College Students, they received seven Provincial Second Prizes and seven Provincial Third Prizes. These competition outcomes are substantial, demonstrating excellent performance at both national and provincial levels, with the number of awards increasing annually.

3. Enhanced Teaching Research by the Team of Instructors

The Advanced Mathematics teaching team has adopted a "competition-promoted teaching" approach and participated in various teaching reform projects at

different levels, achieving notable results. These include the approval of one educational reform project by the Beijing Higher Education Mathematics Research Association in 2025, one university-level teaching reform project in 2024, and one Beijing Digital Education Research project in 2024. Under the broader goal of advancing the construction and reform of the Advanced Mathematics course, team members have actively published multiple teaching reform papers in various journals, led university-level teaching reform initiatives, and contributed to the compilation of teaching support materials. The process of identifying practical cases and preparing appropriate modeling tasks has also broadened the instructors' knowledge and updated their educational philosophies, thereby enhancing their overall teaching proficiency.

V. Conclusion

Guided by a student-centered educational philosophy, we have designed a "Four-Driven, Dual-Track Integrated" teaching model that effectively achieves multi-dimensional integration of theory, knowledge, skills, and online-offline activities. This approach has significantly enhanced students' mathematical thinking, innovative problem-solving abilities, and teamwork skills. In future teaching practices, we will continue to deepen teaching reforms, with a focus on optimizing the process evaluation mechanism, refining the integration of online and offline teaching segments, and improving the scientific organization of teaching and targeted guidance. These efforts aim to further stimulate students' learning potential and consolidate and expand the effectiveness of the teaching reforms.

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